Development of a permanent magnet for a high performance undulator

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A new permanent magnet material (NEOMAX-35H) has been designed for generating high brightness synchrotron radiation. Measuring methods of the magnets and their assembly process are also discussed. It has been proved that the NEOMAX-35H magnet is a suitable magnetic material for undulators and wigglers.

INTRODUCTION

Synchrotron radiation is generated from an electron beam bent by a magnetic field, and it is expected to become a useful tool for various technologies, such as microphysical experiments, medical equipment, etc.

Recently, a new technology has been developed for increasing the brightness and improving the quality of the radiation by inserting a periodic magnetic field source between conventional bending magnets. Such an insertion device is called a wiggler or an undulator, for the electron beam is wiggled by its periodic magnetic field.

The first permanent type of undulator was developed by Halbach in 1981 using a rare earth magnet.[1] Since then the permanent magnet type of undulators has been mainly used because of their economic advantages and compactness in volume compared with those of electromagnetic types.[2]

In this paper, the optimal properties and manufacturing processes of permanent magnets have been investigated for a high performance undulator application.

I. PERMANENT MAGNET FOR UNDULATOR

A. Analysis by finite element method

In order to develop the optimal undulator, required properties of a permanent magnet, such as the allowable variations of its orientation and the maximum demagnetizing field, were analyzed with a two-dimensional finite-element method.[3]

The analytical model in the case of a pure configuration undulator is shown in Fig. 1. Figure 2(a) shows the flux distribution in the undulator calculated when each magnet is oriented correctly, and Fig. 2(b) shows the flux distribution when one magnet in the magnet array has a 10° deviation from the ideal orientation. It is clearly shown from Fig. 2 that the flux distribution in the gap is affected by a moment orientation. Therefore, the moment orientation should be minimized for this undulator.

Also by the above calculations, the maximum demagnetizing field in a permanent magnet is shown to reach 0.9 T. Therefore, the permanent magnet for this undulator must have a coercivity of more than 1000 A/m.

B. Optimal magnetic material

A new Nd-Fe-B (NEOMAX-35H) magnet, the average remanence and coercivity of which are 1.20 T and 1350 A/m, respectively, has been developed in order to satisfy the above requirement.

As reported in the literature,[4] NEOMAX is an anisotropic sintered magnet composed basically of neodymium, iron, and boron. Its main phase is a newly found NdFeB intermetallic compound with a tetragonal crystal structure.

Magnetic and physical properties of various permanent magnets are compared in Table I with those of NEOMAX-35H. Figure 3 shows the demagnetization curve of NEOMAX-35H. It can be said from Table I and Fig. 3 that the NEOMAX-35H developed is suitable for an undulator both in remanence and coercivity.

II. EXPERIMENTAL RESULTS

A. Measuring methods

In order to estimate the magnetic properties precisely for the undulator, the following measuring equipment has

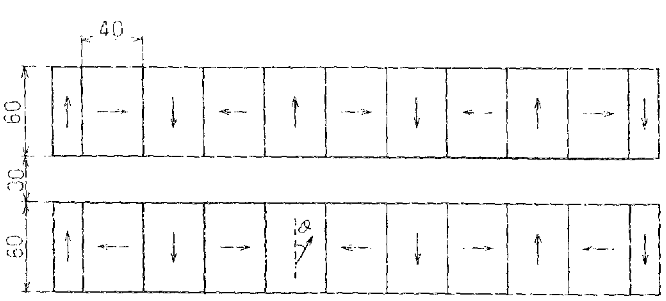

FIG. 1. Analytical model.

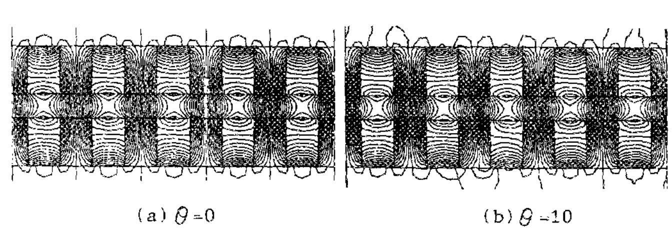

FIG. 2. Flux distribution in undulator.

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TABLE I. Magnetic and physical properties.

	Magnetic properties						Physical properties					
	Remanence Br kG	Coercivity bHC kOe	Coercivity iHC kOe	Maximum energy product (BH)max MGOe	Recoil permeability μrec —	Temp. coeff. of Br %/°C	Density g/cm^3	Electrical resistivity $\mu\Omega$ cm	Vickers hardness Hv	Flexural strength kg/mm^2	Tensile strength kg/mm^2	Coefficient of thermal expansion 10^{-6}/°C
NEOMAX-35H	12.1	11.6	17.0	35.0	1.05	−0.12	7.4	144	600	25	8.0	3.4(∥) −4.8(⊥)
Sm-Co magnet	11.2	6.7	6.9	31.0	1.03	−0.03	8.4	85	550	12	4.5	13
Ferrite magnet	4.4	2.8	2.9	4.6	1.10	−0.18	5.0	$>10^4$	530	13	4.0	13(∥) 8(⊥)
Alnico magnet	11.5	1.6	1.6	11.0	1.30	−0.02	7.3	45	650	—	—	11

been newly developed. (1) Magnetic moment: A Hall probe system used for measurements shown in Fig. 4, where the absolute field strength is calibrated by a NMR method. Its stability and resolution are less than 10 ppm, 0.2%, respectively. (2) Magnetic orientation: A VSM (vibrating sample magnetometer) composed of three pairs of coils (X,Y,Z) has been developed. Its resolution is less than 0.05°.

B. Measured results of magnetic moment and orientation

The orientation of magnetization is measured for each segment, besides measuring the demagnetization curve for several pieces in a lot. NEOMAX-35H segments, whose dimensions are 20×20×126 mm, have been pressed by applying 1.2 T of magnetic field perpendicularly, where the cavity of the tool is set so as to be located at the center of the magnetic field. After sintering, they were machined with specially provided jigs.

Using the six segments, the basic blocks for the undula-

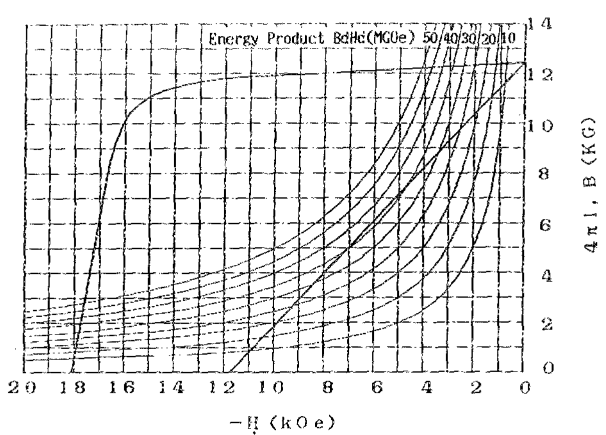

FIG. 3. Demagnetization curve.

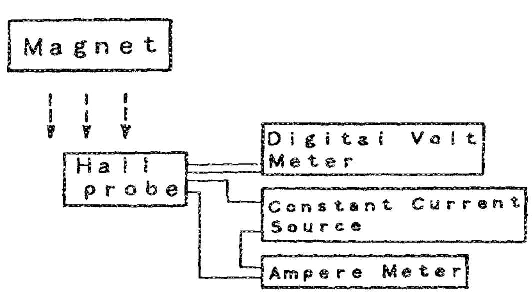

FIG. 4. Hall probe system.

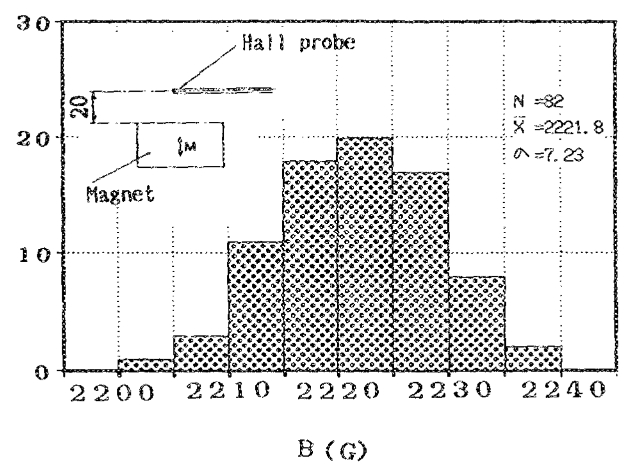

FIG. 5. Variation of magnetic moment.

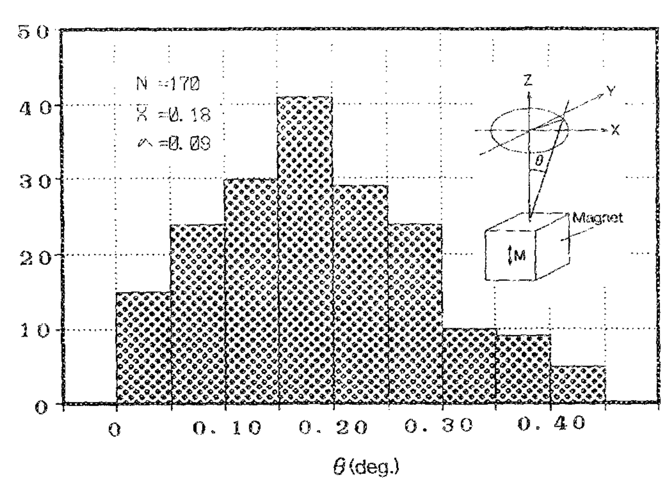

FIG. 6. Variation of orientation.

tor, the dimensions of which are $60 \times 40 \times 126$ mm, are bonded. Each segment was arranged so that the resultant variation of the block showed minimum deviation.

Figure 5 shows the variation of flux density measured at 20 mm from the surface of each block. Figure 6 shows the variation of magnetic orientation. It was proved that the provided magnets have enough strength and precision for the undulator requirements.

III. CONCLUSION

It has been shown that NEOMAX-35H magnets, prepared by the method described in this paper, could satisfy basic required properties for generating a high performance synchrotron radiation.

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